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Physical qualities of an Ultisol under sugarcane and Atlantic forest in Brazil

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ABSTRACT

The objective of this work was to evaluate the soil physical quality of three different sugarcane growing areas and native Atlantic forest. The statistical analysis of the physical properties of the soil showed good accuracy, with adequate coefficients of variation and low Gaussian variability, allowing the correct adjustment of an additive model to determine the physical quality of the soil. Using an additive model and the adjustment of soil physical properties (soil density, total porosity, macroporosity, microporosity, mechanical resistance to penetration, aggregate soil stability and organic matter content), it was possible to determine the physical quality of the soil at each of the experimental sites depending on its capacity for root support and water storage. A cluster analysis grouped the sites based on similarities in their physical property responses; the first group included sites with sugarcane undergoing 44 and 40 years of production, the second group included the sugarcane site with 15 years of production, and last group contained native Atlantic Forest. After the native forest, the sugarcane site with the lowest number of production years presented the best quality, in contrast to the sites with longer production times, with greater changes in soil physical properties in terms of root support capacity. Determining the soil physical quality can help in the management, control and improvement of soil health and agricultural sustainability.

1. Introduction

Over the past few decades, Brazilian agriculture has changed in terms of its production techniques due to technological advancements. Agricultural machinery has intensified the use of agricultural areas; however, the observed low productivity of some areas has often been related to the inappropriate use of technologies, causing economic losses and affecting the environment (Hunke et al., 2015; FAO, 2016).

Sugarcane is one of the most important crops in the world. This crop requires the intensive use of technology, especially in Brazil, which is the greatest producer of sugarcane worldwide due to its importance in the economic and industrial sectors; however, the inadequate and intensive use of machinery has caused soil problems and therefore reduced yields (IBGE, 2013; Aquino et al., 2015; Lima et al., 2015).

Soil compaction is a problem that affects sugarcane crop systems. This problem is mainly caused by the high frequency of uncontrolled use of heavy vehicles, since they change the physical properties of the soil, negatively affecting its quality (Chen and Yang, 2015; Lima et al., 2015).

These agricultural and environmental problems were identified many decades ago, but the concept of soil quality was introduced in the 1990s to control and measure soil status (Doran and Parkin, 1994; Nakajima et al., 2015). Since then, many approaches have been used to estimate soil quality, such as those related to crop yield as a function of soil physical, chemical and biological parameters (Glover et al., 2000; Cruz et al., 2004; Cambi et al., 2015).

Several methodologies for engineering process optimization and mathematical models have been used to create scales and indexes to express soil quality in numerical values to evaluate and measure the soil status and effects of agricultural management practices on the soil (Doran and Parkin, 1994; Glover et al., 2000; Rabbi et al., 2014; Freitas et al., 2012; Nakajima et al., 2015). Such quality index models

Abbreviations: 1L, First sugarcane cycle; 3L, Third sugarcane cycle; 5L, Fifth sugarcane cycle; NF, Native forest; AS, Aggregate stability; ρ_s, Density of solids; ρ_d, Dry bulk density; P_{MAC}, Macroporosity; P_{MIC}, Microporosity; PR, Penetration resistance; $PR\theta_{SAT}$, Penetration resistance of saturated soil; $PR\theta_{\leq 0.1w}$, Penetration resistance with $\leq 0.1\ cm^3\ cm^{-3}$ water in soil; SOM, Soil organic matter; P_T, Total porosity; *B*, Critical value or threshold-base indicator; *L*, Lowest value that a soil property can have; *q*(*FP*), Partial contribution of each principal function; *QI*, Quality indicator of the physical property of the soil; W_n, Relative weights assigned to each indicator; *qRSC*, Root support capacity; *S*, Slope of the tangent to the curve; *SPQI*, Soil physical quality index; *SQI*, Soil quality index; *v*, Standardized score; I_n, Values of the different indicators; *qWSC*, Water storage capacity; CV, Coefficient of variation; K-S, Kolmogorov–Smirnov test

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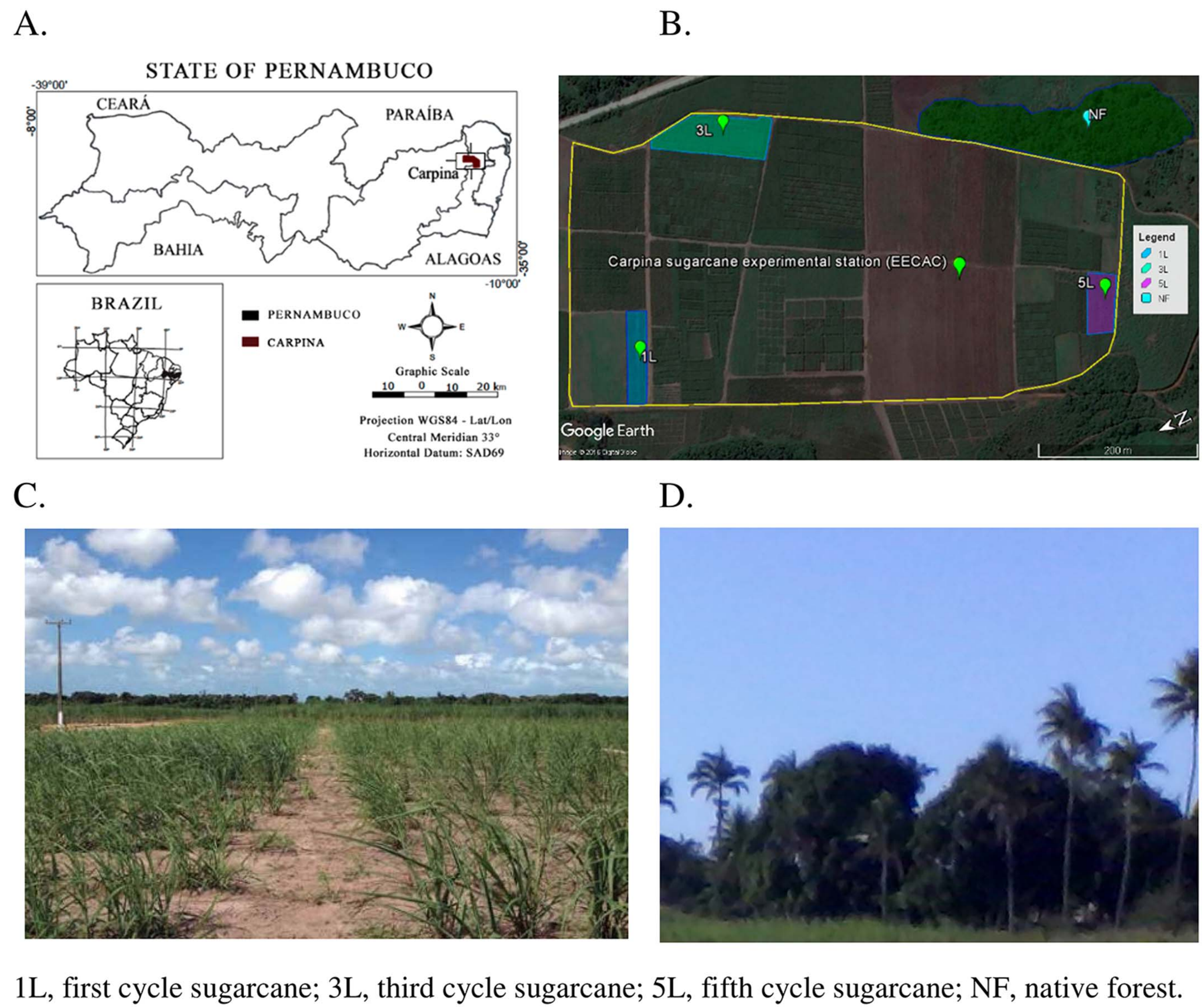

Fig. 1. Location of the Experimental Sugarcane Station of Carpina, State of Pernambuco, Brazil, and scheme of the study site.

individually evaluate soil properties by assessing the responses of these properties to different conditions or treatments, establishing quality scales and limits, and processing this information to obtain a single value representing the soil quality or current status (Wymore, 1993; Karlen et al., 2003).

Considering soil degradation and the need to develop more sustainable agricultural models, the objective of this work was to determine and compare soil physical statuses through the physical quality index in different sugarcane-producing and native Atlantic Forest areas.

2. Materials and methods

2.1. Study site

The study was carried out in Carpina, state of Pernambuco (7°51′13″S, 35°14′10″W and altitude of 180 m) (Fig. 1A). According to the Köppen classification, the climate of the region is megathermal (As′), hot and humid. The region presents a natural vegetation of tropical rainforest, an annual average temperature of ~26 °C (~30 °C to ~22 °C), annual average precipitation of ~1200 mm (2015) and relative humidity of ~70% (Lima et al., 2015). The soil of the study sites is an Ultisol of sandy-loam texture and is characterized in Table 1. Such soils are mineral soils that are red-yellow in colour, usually found in the coastal region of Brazil and characterized by some limited agriculture, e.g., low fertility, high infiltration and natural cohesiveness that hinders the penetration of roots.

Table 1
General characterization of the areas with sugarcane crops (1L, 3L and 5L) and native Atlantic Forest (NF).

Characteristics	Soil use			
	1L	3L	5L	NF
Years of sugarcane production	44	40	15	–
Production cycle (years)	1	3	5	–
Slope (%)	≤1			
Soil texture	Sandy loam			
Sand (g kg^{-1})	866.00	877.17	869.50	738.67
Silt (g kg^{-1})	43.50	34.50	39.83	142.00
Clay (g kg^{-1})	90.50	88.33	90.67	119.33
Density (ρ_s) (g cm^{-3})	2.69	2.67	2.69	2.62

The study sites occurred in sugarcane-producing areas and native Atlantic forest. At the first site with sugarcane, the crop production (1L) was in the first cycle (1st of five years) in a field with 44 years of soil